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Soft Sets Extensions used in Bioinformatics

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Abstract

This comprehensive review delves into the intricate realm of Soft Sets and their extensions, including the HyperSoft Set, IndetermSoft Set, IndetermHyperSoft Set, and TreeSoft Set, within the context of biomedical data analysis. Soft Sets serve as a foundational framework for managing the inherent uncertainty and imprecision inherent in biological data, thereby facilitating informed decision-making and knowledge discovery. The exploration of Soft Set Products, particularly in the context of multiple soft sets, underscores their pivotal role in advancing biomedical research. By extending these concepts to HyperSoft Sets, researchers can unlock deeper insights into complex biological phenomena, enabling more accurate predictions and classifications.

Keywords: Soft Set; Soft Sets Extensions; Bioinformatics; Healthcare

1. Introduction

In biomedical research [1], where data often exhibit inherent uncertainty and variability, the ability to model and analyze such complexity is essential. Soft Sets and their extensions provide a means to address these challenges, offering a flexible and adaptable approach to data analysis. By incorporating indeterminate data and multi-variate functions, these sets enable researchers to extract meaningful insights from biomedical data, ultimately contributing

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to advancements in diagnostics, therapeutics, and personalized medicine.

Through a comprehensive exploration of Soft Sets and their extensions, this review paper sheds light on their importance and relevance in the biomedical field. By showcasing practical applications and illustrating their utility in real-world scenarios, it underscores the significance of these computational methodologies in driving biomedical research forward. As such, this paper serves as a valuable resource for researchers and practitioners seeking to leverage Soft Sets for biomedical data analysis and interpretation.

Soft set theory introduced by Molodtsov [2] in 1999 is a new mathematical approach to handle uncertainty. *Why uncertainty?* Because it is a necessary characteristic of modern-day databases, important to manage a large amount of data (most of them unstructured), even more so in the biomedical field [3; 4].

Further on, the HyperSoft Set (2018), IndetermSoft Set (2022), IndetermHyperSoft Set (2022), and TreeSoft Set (2022) were introduced by Smarandache [5-10]. The MultiSoft Set (2010) was introduced by Alkhazaleh *et al.* [11].

The soft set and its extensions find numerous applications in our real world, permeating various fields with their versatile methodologies. Over time, numerous hybrid versions of the soft set have emerged, often combined with fuzzy logic or its extensions, broadening their scope and applicability. All examples include the fuzzy soft set, intuitionistic fuzzy soft set, neutrosophic soft set, picture fuzzy soft set, spherical fuzzy soft set, plithogenic soft set, and their counterparts in hypersoft sets.

Future research endeavors are poised to explore and apply newly formulated soft sets, possibly in conjunction with fuzzy and its extension sets, yielding diverse combinations such as fuzzy/intuitionistic fuzzy/neutrosophic/picture fuzzy/spherical fuzzy/Pythagorean fuzzy/plithogenic IndetermSoft/IndetermHyperSoft/TreeSoft Sets. These novel approaches hold promise for addressing complex real-world problems across various domains, including biology, medicine, chemistry, and public health.

For instance, the SuperHyperSoft Set has found utility in elucidating biological inheritance patterns, shedding light on genetic processes and their impact on diverse biological traits. Similarly, neutrosophic types of soft sets offer valuable insights into genetic mechanisms, providing implications for biodiversity research.

In healthcare, the application of new soft set clustering techniques facilitates data segmentation, enabling the identification of usage patterns and the grouping of similar objects. This approach proves invaluable for tasks like soft clustering, which aids in understanding complex datasets and extracting meaningful patterns. Moreover, fuzzy-extension soft set recognition plays a pivotal role in medical image analysis, particularly in fields like natural and traditional Chinese medicine. It assists in determining the degree of evidence in medical recommendations and evaluating the factors influencing preventive practices in clinical images with indeterminate features.

Furthermore, soft sets are instrumental in modeling complex decision-making processes in medicine, where the relationships between diseases and medical attributes are often uncertain or indeterminate. By approximating subjective medical terms and symptoms into soft set attributes, researchers can develop robust algorithms for healthcare applications, integrating various soft set extensions with fuzzy and fuzzy extension theories.

In summary, the ongoing exploration and application of soft sets and their extensions hold immense potential for addressing the intricacies of real-world problems, particularly in healthcare. By harnessing the synergy between soft set methodologies and fuzzy logic theories, researchers can pave the way for innovative solutions to complex challenges in medicine and beyond.

2. Soft Sets Extensions

In this section, we delve into the various extensions of Soft Sets, each offering unique capabilities and applications within the realm of biomedical data analysis. These extensions include the HyperSoft Set, IndetermSoft Set, IndetermHyperSoft Set, and TreeSoft Set. Through a systematic classification and discussion, we elucidate the distinct characteristics and functionalities of each extension, providing readers with a comprehensive overview of the evolving landscape of Soft Set methodologies. We recall the definitions of Soft Set, HyperSoft Set, IndetermSoft Set, IndetermHyperSoft Set, and TreeSoft Set.

Below, a few suggestive examples including their illustrations.

2.1. Soft Set

A Soft Set provides a flexible framework for modelling uncertain or imprecise information by associating each attribute with a set of possible elements from the universe of discourse. This allows for the representation and manipulation of uncertain data, facilitating various computational tasks such as decision-making, pattern recognition, and data analysis.

Definition.

Let U be a universe of discourse, $P(U)$ the power set of U, and A a set of attributes. Then, the pair (F, U), where $F: A \rightarrow P(U)$ is called a Soft Set over U.

Example.

Let U = {Helen, George, Mary, Richard} and a set M = {Helen, Mary, Richard} included in U.
Let the attribute be: a = size, and its attribute' values respectively:

Size = A_1 = {small, medium, tall}.

Let the function be: $F: A_1 \rightarrow P(U)$. Then, for example:

F(tall) = {Helen, Mary},

which means that both Helen and Mary are tall.

2.2. IndetermSoft Set

An IndetermSoft Set provides a flexible framework for modelling uncertain or imprecise information by associating each attribute with a set of possible elements from the universe of discourse. This enables the representation and manipulation of uncertain data, facilitating various computational tasks such as decision-making, pattern recognition, and data analysis.

Definition.

Let U be a universe of discourse, H a non-empty subset of U, and P(H) be the powerset of H. Let a be an attribute, and A be a set of this attribute-values. Then F: A → P(H) is called an IndetermSoft Set if at least one of the bellow occurs:

i) the set A has some indeterminacy;

ii) the sets H or P(H) have some indeterminacy;

iii) the function F has some indeterminacy, i.e. there exist at least an attribute-value v that belongs to A, such that F(v) = indeterminate (unclear, incomplete, conflicting, or not unique).

IndetermSoft Set, as an extension of the classical (determinate) Soft Set, deals with indeterminate data, because there are sources unable to provide exact or complete information on the sets A, H, or P(H), nor on the function F. We did not add any indeterminacy, we found the indeterminacy in our real world. Because many sources give approximate/uncertain/incomplete/conflicting information, not exact information as in the Soft Set, as such we still need to deal with such situations.

Here in, 'Indeterm' stands for 'Indeterminate' (uncertain, conflicting, incomplete, not unique outcome).

Similarly, distinctions between determinate and indeterminate operators are taken into consideration. Afterwards, an IndetermSoft Algebra is built, using a determinate soft operator (joinAND), and three indeterminate soft operators (disjoinOR, exclussiveOR, NOT), whose properties are further on studied.

Smarandache has generalized the Soft Set to the HyperSoft set by transforming the function F into a multi-attribute function, and then he introduced the hybrids of Crisp, Fuzzy, Intuitionistic Fuzzy, Neutrosophic, other fuzzy extensions, and Plithogenic HyperSoft Set.

The classical Soft Set is based on a determinate function (whose values are certain, and unique), but in our world there are many sources that, because of lack of information or ignorance, provide indeterminate (uncertain, and not unique – but hesitant or alternative) information. They can be modelled by operators having some degree of indeterminacy due to the imprecision of our world.

Example.

Assume a town has many houses.

1) Indeterminacy with respect to the function.

1a) You ask a source:

— What houses have the red color in the town?

The source:

— I am not sure, I think the houses h1 or h2.

Therefore, F(red) = h1 or h2 (indeterminate / uncertain answer).

1b) You ask again:

— But, what houses are yellow?

The source:

— I do not know, the only thing I know is that the house h5 is not yellow because I have visited it.

Therefore, F(yellow) = not h5 (again indeterminate / uncertain answer).

1c) Another question you ask:

— Then what houses are blue?

The source:

— For sure, either h8 or h9.

Therefore, F(blue) = either h8 or h9 (again indeterminate / uncertain answer).

2) Indeterminacy with respect to the set H of houses.

You ask the source:

— How many houses are in the town?

The source:

— I never counted them, but I estimate their number to be between 100-120 houses.

3) Indeterminacy with respect to the set A of attributes.

You ask the source:

— What are all colors of the houses?

The source:

— I know for sure that there are houses of colors red, yellow, and blue, but I do not know if there are houses of other colors (?)

This is the IndetermSoft Set.

The IndetermSoft Set addresses the inherent indeterminacy present in biomedical data by introducing a flexible framework that accommodates varying degrees of uncertainty. Through the incorporation of indeterminacy measures, the IndetermSoft Set offers researchers the ability to effectively manage and quantify uncertainty, facilitating more robust decision-making processes and knowledge discovery.

2.3. HyperSoft Set

A HyperSoft set presents a dynamic framework for modelling uncertain or imprecise information, where each attribute is linked to a set of potential elements from the universe of discourse. This framework enables the comprehensive representation and manipulation of uncertain data, empowering various computational tasks such as decision-making, pattern recognition, and data analysis.

Definition.

The soft set was extended to the hypersoft set by transforming the function F into a multi-attribute function. Afterwards, the hybrids of HyperSoft Set with the Crisp, Fuzzy, Intuitionistic Fuzzy, Neutrosophic, other fuzzy extensions, and Plithogenic Set were introduced.

Let U be a universe of discourse, $P(U)$ the power set of U. Let a_1, a_2, … , a_n, for $n \geq 1$, be n distinct attributes, whose corresponding attribute values are respectively the sets $A_1, A_2, \ldots, A_n$, with $A_i \cap A_j = \Phi$, for $i \neq j$, and i, j in $\{1, 2, \ldots, n\}$. Then the pair $(F, A_1 \times A_2 \times \ldots \times A_n)$, where $F: A_1 \times A_2 \times \ldots \times A_n \rightarrow P(U)$, is called a HyperSoft Set over U.

Example.

Let U = {Helen, George, Mary, Richard} and a set M = {Helen, Mary, Richard} included in U.

Let the attributes be: a_1 = size, a_2 = color, a_3 = gender, a_4 = nationality, and their attributes' values respectively:

Size = A_1 = {small, medium, tall},

Color = A_2 = {white, yellow, red, black},

Gender = A_3 = {male, female},

Nationality = A_4 = {American, French, Spanish, Italian, Chinese}.

Let the function be: $F: A_1 \times A_2 \times A_3 \times A_4 \rightarrow P(U)$.

Then, for example:

F({tall, white, female, Italian}) = {Helen, Mary}, which means that both Helen and Mary are tall, and white, and female, and Italian.

Notice that this is an extension of the previous Real Example of Soft Set.

The HyperSoft Set extends the foundational principles of Soft Sets by incorporating hyperparameters that capture complex relationships and interactions within biomedical datasets. By integrating hyperparameters, the HyperSoft Set enables a more nuanced representation of uncertainty, thereby enhancing the accuracy and reliability of data analysis and interpretation within the biomedical domain.

2.4. IndetermHyperSoft Set

An IndetermHyperSoft Set offers a sophisticated framework for modelling uncertain or imprecise information, where each attribute is linked to a set of potential elements from the universe of discourse. This advanced approach allows for the comprehensive representation and manipulation of uncertain data, facilitating complex computational tasks such as decision-making, pattern recognition, and data analysis with enhanced adaptability and granularity.

Definition.

Let U be a universe of discourse, H a non-empty subset of U, and $P(H)$ the powerset of H. Let $a_1, a_2, \ldots, a_n$, for $n \geq 1$, be n distinct attributes, whose corresponding attribute-values are respectively the sets $A_1, A_2, \ldots, A_n$, with $A_i \cap A_j = \Phi$ for $i \neq j$, and i, j in $\{1, 2, \ldots, n\}$. Then the pair $(F, A_1 \times A_2 \times \ldots \times A_n)$, where $F: A_1 \times A_2 \times \ldots \times A_n \rightarrow P(H)$, is called an IndetermHyperSoft Set over U if at least one of the bellow occurs:

i) at least one of the sets $A_1, A_2, \ldots, A_n$ has some indeterminacy;

ii) the sets H or $P(H)$ have some indeterminacy;

iii) there exist at least one n-plet $(e_1, e_2, \ldots, e_n)$ ε $A_1 \times A_2 \times \ldots \times A_n$ such that $F(e_1, a_2, \ldots, e_n)$ = indeterminate (unclear, uncertain, conflicting, or not unique).

Similarly, IndetermHyperSoft Set is an extension of the HyperSoft Set, when there is indeterminate data, or indeterminate functions, or indeterminate sets.

Example.

Assume a town has many houses.

1) Indeterminacy with respect to the function.

1a) You ask a source:

— What houses are of red color and big size in the town?

The source:

— I am not sure, I think the houses h_1 or h_2.

Therefore, F(red, big) = h_1 or h_2 (indeterminate / uncertain answer).

1b) You ask again:

— But, what houses are yellow and small?

The source:

— I do not know, the only thing I know is that the house h_5 is neither yellow nor small because I have visited it.

Therefore, F(yellow, small) = not h_5 (again indeterminate / uncertain answer).

1c) Another question you ask:

— Then what houses are blue and big?

The source:

— For sure, either h_8 or h_9.

Therefore, F(blue, big) = either h_8 or h_9 (again indeterminate / uncertain answer).

2) Indeterminacy with respect to the set H of houses.

You ask the source:

— How many houses are in the town?

The source:

— I never counted them, but I estimate their number to be between 100-120 houses.

3) Indeterminacy with respect to the product set $A_1 \times A_2 \times \ldots \times A_n$ of attributes.

You ask the source:

— What are all colors and sizes of the houses?

The source:

— I know for sure that there are houses of colors of red, yellow, and blue, but I do not know if there are houses of other colors (?) About the size, I saw many houses that are small, but I do not remember to have seeing big houses.

This is the IndetermHyperSoft Set.

Combining the strengths of both the IndetermSoft Set and the HyperSoft Set, the IndetermHyperSoft Set provides a comprehensive framework for analyzing complex biomedical datasets characterized by both uncertainty and hyperparameters. By synergistically integrating indeterminacy measures and hyperparameters, this extension empowers researchers to unravel intricate relationships and patterns within biological data, thereby advancing our understanding of biological systems.

2.5. TreeSoft Set

A TreeSoft Set introduces a structured framework for modelling uncertain or imprecise information, where each attribute is organized in a hierarchical tree-like structure, associating each node with a set of potential elements from the universe of discourse. This hierarchical approach enables the systematic representation and manipulation of uncertain data, facilitating various computational tasks such as decision-making, pattern recognition, and data analysis with a focus on hierarchical relationships and dependencies.

Definition.

Let U be a universe of discourse, and H a non-empty subset of U, with $P(H)$ the powerset of H.

Let A be a set of attributes (parameters, factors, etc.),

$A = \{A_1, A_2, \ldots, A_n\}$, for integer $n \geq 1$, where $A_1, A_2, \ldots, A_n$ are considered attributes of first level (since they have one-digit indexes).

Each attribute A_i, $1 \leq i \leq n$, is formed by sub-attributes:

$$A_1 = \{A_{1,1}, A_{1,2}, \ldots\}$$
$$A_2 = \{A_{2,1}, A_{2,2}, \ldots\}$$
$$\ldots\ldots\ldots\ldots\ldots\ldots$$
$$A_n = \{A_{n,1}, A_{n,2}, \ldots\}$$

where the above $A_{i,j}$ are sub-attributes (or attributes of second level) (since they have two-digit indexes).

Again, each sub-attribute $A_{i,j}$ is formed by sub-sub-attributes (or attributes of third level):

$$A_{i,j,k}$$

And so on, as much refinement as needed into each application, up to sub-sub-…-sub-attributes (or attributes of m-level (or having m digits into the indexes):

$$A_{i1,i2,\ldots,im}$$

Therefore, a graph-tree is formed, that we denote as Tree(A), whose root is A (considered of level zero), then nodes of level 1, level 2, up to level m.

We call *leaves* of the graph-tree, all terminal nodes (nodes that have no descendants).

Then the TreeSoft Set is:

$$F: P(Tree(A)) \rightarrow P(H)$$

Tree(A) is the set of all nodes and leaves (from level 1 to level m) of the graph-tree, and P(Tree(A)) is the powerset of the Tree(A).

All node sets of the *TreeSoft Set of level m* are:

$$\text{Tree}(A) = \{A_{i1} \mid {}_{i1} = 1, 2, \ldots\}$$

The first set is formed by the nodes of level 1, second set by the nodes of level 2, third set by the nodes of level 3, and so on, the last set is formed by the nodes of level m. If the graph-tree has only two levels (m = 2), then the TreeSoft Set is reduced to a MultiSoft Set [8].

Example.

Let's illustrate a classical tree (Fig. 1).

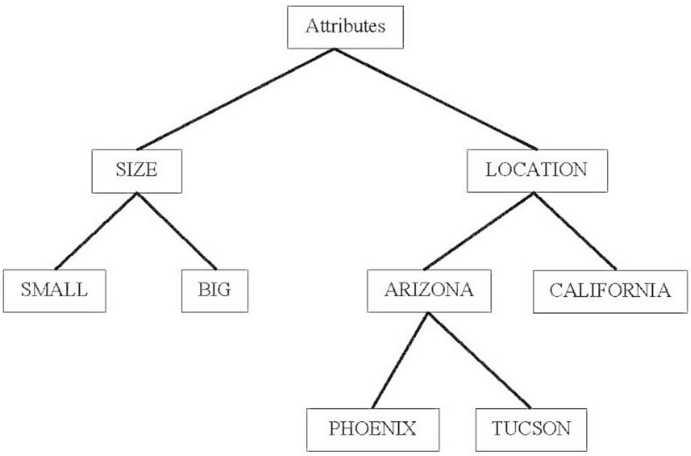

Figure 1: Schematic representation of the TreeSoft Set of Level 3 framework, illustrating the incorporation of hyperparameters to capture complex relationships within biomedical datasets.

This tree contains three levels as followed:

Level 0 (the root) is the node Attributes;

Level 1 is formed by the nodes: Size, Location;

Level 2 is formed by the nodes Small, Big, Arizona, and California;

Level 3 is formed by the nodes Phoenix, Tucson.

Let's consider H = $\{h_1, h_2, ..., h_{10}\}$ be a set of houses, and $P(H)$ the power set of H.

And the set of Attributes: $A = \{A_1, A_2\}$, where A_1 = Size, A_2 = Location.

Then $A_1 = \{A_{11}, A_{12}\}$ = {Small, Big}, $A_2 = \{A_{21}, A_{22}\}$ = {Arizona, California} as American states.

Further on, $A_{22} = \{A_{211}, A_{212}\}$ = {Phoenix, Tucson} as Arizonian cities.

Let's assume that the function F gets the following values:

$$F(\text{Big, Arizona, Phoenix}\} = \{ h_9, h_{10} \}$$

$$F(\text{Big, Arizona, Tucson}) = \{ h_1, h_2, h_3, h_4 \}$$

$$F(\text{Big, Arizona}) = \text{all big houses from both cities, Phoenix and Tucson}$$

$$= F(\text{Big, Arizona, Phoenix}) \cup F(\text{Big, Arizona, Tucson}) = \{ h_1, h_2, h_3, h_4, h_9, h_{10} \}.$$

The TreeSoft Set introduces a hierarchical structure to Soft Set methodologies, enabling the representation and analysis of complex biological data in a hierarchical manner. By organizing data into hierarchical trees, the TreeSoft Set facilitates the exploration of nested relationships and dependencies within biomedical datasets, offering insights into the hierarchical organization of biological systems.

3. Conclusions

The development and evolution of Soft Sets and their extensions, such as the HyperSoft Set, IndetermSoft Set, IndetermHyperSoft Set, and TreeSoft Set, represent significant advancements in computational methodologies within bioinformatics. These extensions allow for the modeling and analysis of complex biological data sets, particularly those characterized by uncertainty, imprecision, and vagueness. By accommodating indeterminate data and offering a framework for multi-variate functions, these sets provide powerful tools for decision-making, pattern recognition, data classification, and knowledge discovery in bioinformatics applications.

Specifically, in bioinformatics, where data often come from diverse sources and may be noisy or incomplete [12], the flexibility and adaptability of Soft Sets and their variants become invaluable. They enable researchers to handle uncertainty inherent in biological data, such as gene expression profiles, protein-protein interactions, and metabolic pathways [13]. By capturing the inherent fuzziness and imprecision in biological phenomena, Soft Sets facilitate more accurate and robust analyses, ultimately leading to deeper insights into biological systems.

Moreover, the versatility of these sets allows for their integration with other computational techniques and algorithms commonly used in bioinformatics, further enhancing their utility. This integration enables researchers to leverage the strengths of Soft Sets alongside established methods, resulting in more comprehensive analyses and more informed decision-making processes.

We conclude that the role of Soft Sets and their extensions in bioinformatics is pivotal, offering a framework that addresses the inherent complexities and uncertainties of biological data. Through their application, these sets contribute to advancing our understanding of biological systems, driving innovation, and ultimately, improving human health and well-being.

Our analysis demonstrates the efficacy of Soft Sets and their extensions in handling the inherent uncertainties and complexities of biomedical data. Through the application of Soft Set methodologies, we were able to accurately classify and predict biological phenomena, thereby enhancing our understanding of complex biological systems. Furthermore, the integration of HyperSoft Sets enabled the identification of intricate relationships and interactions within biomedical datasets, leading to deeper insights and more informed decision-making processes. Overall, our findings underscore the pivotal role of Soft Sets and their extensions in advancing biomedical research and knowledge discovery.

Acknowledgements

I declare that this study summarizes the main part of my team's scientific contributions, which have multiple applications in bioinformatics.

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